SURVEYOR SITE CERTIFICATION STUDY

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PURPOSE AND SCOPE

This paper is a trial run of a systematic study of follow-on Surveyor instrumentation, with the single aim of Apollo site certification. It is intended to be a guide to a more complete and definitive study, which should result in a logical plan for follow-on Surveyor support to Apollo.

ABSTRACT

A complete set of possible lunar surfaces is generated, described in terms of four principal parameters: bearing strength, small-scale roughness, large-scale roughness, and uniformity. Follow-on Surveyor instruments necessary to certify each surface are defined, and the instruments are grouped into alternate follow-on payloads; each payload is superior for a particular group of surfaces, but there are some surfaces which resist certification by either of the suggested alternate payloads.

It is concluded that the principle of alternate follow-on payloads optimized for different groups of possible surfaces is a valid one, but that a much more extensive study is needed before exact payloads can be defined.

SURVEYOR SITE CERTIFICATION STUDY

1.0 OBJECTIVE

The follow-on Surveyor program (together with the Lunar Orbiter program) has been given responsibility for selecting and certifying the first Apollo landing site. In order to do this, the follow-on Surveyor instrument payloads must be optimized for the job of site certification*. The present study is intended to be rough cut at defining these payloads. No claim is made for the completeness of the study or for the specific payloads which result; the motivation for doing it was to test the approach rather than to arrive at specific payloads. A much more complete analysis is needed, along similar lines, before an optimum set of payloads can be designed. It is, however, believed that all major elements of such an analysis are illustrated in this report.

2.0 INTRODUCTION

A complete site certification program requires the complementary use of Surveyor and Lunar Orbiter. Since the requirements which must be placed on each depend to some extent on the characteristics of the other, a brief discussion of the combined mission is desirable here.

The early operational Surveyors (5-8) are incapable of direct contribution to site certification, since they

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* The characteristics of an acceptable site are presented in Requirements for Data in Support of Project Apollo, Issue III (Draft), Bellcomm, Inc., November 18, 1963.

have a limited payload weight and some scientific objectives. They will, however, yield data which will help to classify the surface in a general way. The follow-on Surveyor payloads may then be chosen to yield a maximum of information from the type of surface predicted by the early operational Surveyors.

Lunar Orbiters likewise have two distinct missions. Since the moon is not uniformly smooth and flat, there are some areas which are likely to be unsuitable for a Surveyor landing (as well as for a LEM landing); Orbiters will be useful here to screen out the unsuitable areas, at a photographic resolution over two orders of magnitude finer than that obtainable from earth*. Also, the resolution of Surveyor television falls off rapidly with increasing distance. The result is that the area in which the TV can detect objects of the order of 2 feet in diameter (the smallest obstacle which is individually dangerous to the LEM) is a very small fraction indeed of the area which must be certified. Here the Orbiter is intended to overfly the landed Surveyor and photograph the same area**. In this way it allows extrapolation to areas the Surveyor cannot see, on the basis of joint observation of areas that Surveyor can see. (Surveyor can view a small area at very

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* The RFP (Langley Research Center) calls for a resolution of 8 meters per optical line pair in the wide coverage mode.

** The RFP calls for a resolution of 1 meter per optical line pair in the high resolution mode.

high resolution; Orbiter can view a much larger area at somwhat poorer resolution.)

Thus the site certification program consists of:

a) early operational Surveyors to classify the surface.

b) Orbiters to screen out rough landing areas for follow-on Surveyors (and early Surveyors as well, if Orbiters are ready in time).

c) follow-on (f/o) Surveyors to make tactile measurements of the surface and to photograph the immediate vicinity -- partial certification.

d) Orbiters to overfly the landed f/o Surveyors and complete the certification of landing sites.

There remains only the problem of designing the payloads for the follow-on Surveyors. Logically, one would expect to complete the task of classification of the surface before designing a f/o payload which is optimum for that surface; the difficulty with this procedure is the two or three year development time required to produce such payloads, which process could only begin after the classification job is finished. Much time can be saved by planning now for contingencies, developing alternate sets of instruments for use on different anticipated surfaces. The intent is to have alternate complete integrated follow-on payloads developed and ready to fly, so that information returned by early operational Surveyors and Lunar Orbiters will permit selection of the follow-on payload actually to be flown with minimum delay.

This procedure requires slightly broader specifications for the payloads: Not only must each accurately describe the surface for which it was designed, but it must

also confirm that we "guessed right" in selecting it as the one to be flown. Most payloads that can certify sites are inherently able to make such a confirmation.

The approach used in this study is to generate a set of hypothetical (but geologically reasonable) lunar surfaces sufficiently broad to ensure that the actual lunar surface is included. For each surface, a number of measurements adequate to describe it are listed, and instruments capable of these measurements are defined (in most cases, these instruments have already reached the hardware stage). The critical parameters of these instruments are delineated, and they are then compared with parameters of instruments currently being developed. Finally, the instruments are grouped into payloads in the hope that every likely surface can be certified by at least one of the payloads.

The systematic process used here was intended for a much more detailed study than the present one. This paper was meant primarily to test the approach for the later study and to serve as a guide for it.

3.0 SURFACES AND MEASUREMENTS

An attempt will be made to generate a complete list of hypothetical lunar surfaces, so as to assure that the actual lunar surface is included. The surfaces are described in terms of those parameters which are significant to the Apollo landing situation.

Four parameters are used to describe a surface:

a) bearing strength

b) small-scale roughness (comparable in dimension to a LEM landing pad)*
c) large-scale roughness (hills and valleys, or dunes)
d) uniformity over an area comparable in size to twice the LEM CEP*.

For a given surface, each parameter is assigned the value "0" or "1" -- the former if that parameter does not represent a hazard to the Apollo LEM, and the latter if it may represent a hazard. The four parameters thus generate a four-bit binary coding, consisting of sixteen possible codes. To the extent that these four parameters describe a hypothetical surface, the sixteen binary codes which are formed in the above way describe all possible surfaces.

The parameter values are assigned in the following manner:

a) Bearing strength is coded "0" if the surface is strong enough to support the Apollo LEM with minimum sinkage (for example, 10 psi/foot sinkage or stronger); it is coded "1" if the surface is so weak that it may result in excessive sinkage of the LEM (for example, 1 psi/foot or weaker).

b) Small-scale roughness is coded "0" if rocks and craters of a size which could damage the LEM or interfere with its landing (rocks 2 feet in diameter or larger and craters 3 feet in diameter or larger) are rare; it is coded "1" if such obstacles are common enough to result in more than a 1% chance of failure of a random LEM landing. Note that if the chance of failure of a random landing is 10% or 50% in some areas, the surface could be very rough indeed in those areas; the coding is still simply "1".

c) Large-scale roughness is coded "0" if the surface is flat enough to cause no instability problems during a LEM landing (for example, slopes no greater than a few degrees); it is coded "1" if there are slopes which may cause the LEM to tip (for example, slopes of the order of 10° or greater).

* A LEM landing pad is about 3 feet in diameter; the LEM CEP is about 1 mile in diameter.

d) Uniformity is coded "0" if the surface is uniform in each of the other three parameters that is coded "1", over an area comparable in size to (or larger than) twice the LEM CEP.
Uniformity is coded "1" if the surface is not uniform in each of the other three parameters that is coded "1".
Nonuniformity implies that there may be distant areas that are more hospitable than the nearby one. If one of these areas is as large as twice the LEM CEP, it may be certifiable.

Thus the binary code 0000 defines a surface which is hard, smooth, flat, and uniform -- a "Daytona Beach" surface; the code 0101 defines a surface which is hard, replete with meter-scale obstacles and holes, flat, and which has some areas which are free of small-scale roughness; and other surfaces are described in a similar way.

One of the sixteen codes corresponds to a surface which defies the rules of the coding (0001) -- this is termed a "don't care" condition, and is not considered further.

A complete list of surfaces is given in Appendix A, along with a brief discussion of measurements and instruments. A more detailed study will be made here of three representative surfaces (0110, 1000, and 1001).*

0110 - hard, small-scale roughness, hills and valleys, uniform

Since the surface is assumed to be hard (from data returned by early Surveyors), the verification of

* A complete statistical analysis of the probability of certification of surface 1110 by an assumed set of instruments is presented in An Analysis of Lunar Site Survey by the Unmanned Program, by C. J. Byrne, R. F. Fudali, M. A. Leibowitz, and T. L. Powers; Bellcomm, Inc., January 31, 1964.

this fact is simply the problem of sampling from a single-mode distribution, where nearly all of the distributed values lie on the hard side of the threshold value. Only enough measurements are needed to assure that the surface is hard enough (with reasonable confidence) if all of the samples show it to be hard. If some samples are hard and some soft, the assumption must be called false, and either a different area must be investigated or a payload capable or more and better soil mechanics measurements must be used in the same area. Hardness can be verified by a fairly accurate bearing strength or penetrometer measurement near the Surveyor spacecraft, plus a number of simple omnidirectional accelerometers at various distances away from it.

The surface is assumed to be rough on a small scale, due perhaps to blocky lava flows and meteorite cratering, and possibly too rough for a safe LEM landing. Thus an accurate measurement of the area density of rocks and craters is necessary to determine the confidence with which the LEM may land safely. Good roughness statistics depend on

a) detection of rocks and craters -- controlled by TV resolution, lighting contrast, system S/N, etc. (see Appendix B)
b) measurement of range of rocks and craters (distance from Surveyor) -- controlled by stereo boresight accuracy of the TV cameras (see Appendix C).
c) measured size of rocks and craters -- controlled by range and TV resolution (see Appendix C).

Measurement of roughness thus requires stereo TV, with high resolution, good S/N, and good boresight accuracy.

This is best achieved by mounting two TV cameras firmly to a rigid horizontal bar which can rotate over about 360 degrees of azimuth. Such an arrangement should yield a boresight accuracy of about one minute of arc (see Appendix C).

Hills and valleys contribute an average slope to a potential LEM landing point, which tends to cause the LEM to tip. Measurement of this slope is thus important, and can be made in three ways:

a) photometrically, by TV (inaccurate, since the lunar photometric function is not precisely known at the pertinent sun angles, and since the contrast is low)
b) geometrically, by TV (better, since the boresight accuracy is assumed good)
c) directly, by a roving vehicle equipped with a clinometer (best, if the surface roughness is not so great as to immobilize the rover -- this rover requires direct communication with earth since the hills could block contact with the landed Surveyor).

Neither of the first two ways can be used to measure slopes of only a few degrees or less which cover a very large area. Another effect of the hills and valleys is to block the view of the Surveyor TV cameras, which affects the area over which they can measure small-scale roughness. This makes it necessary to elevate the TV camera bar considerably, in order to permit the cameras to see over moderate-sized hills (see Appendix B).

Since the surface is assumed to be generally uniform (which assumption can be verified by the Orbiter), the Surveyor measurements can be extrapolated to areas beyond the Surveyor's horizon or rover range by use of Orbiter photographs.

1000 - soft, smooth, flat, and uniform

The surface softness is most likely due to a soft dust overlay on a subsurface that is hard and strong; the critical measurements are then the depth and the bearing strength of the soft surface material. The best choice of instrument really depends on the specific type of soft dust: if the dust strength is close to the minimum needed to support the LEM, an instrument which makes a precise measurement of bearing strength at many points on the surface is most appropriate; if the dust is clearly incapable of supporting the LEM, but is somewhat variable in depth, a penetrometer (which accurately measures depth only) would be adequate. In either case a large number of measurements is necessary, in order to make a good statistical sampling.

This kind of measurement can be done really well only by one of the above instruments carried on a roving vehicle, so that the combination can make many precise measurements over a broad area. The only disadvantage here might be that the rover itself would sink into the soft surface. This is unlikely since in such circumstances the parent Surveyor would probably not have landed successfully. An alternative to the instrumented rover, although inferior, is a fixed penetrometer or bearing strength instrument combined with multiple accelerometers launched from the Surveyor. The accelerometers can give an indication of the extent of the soft-overlay region, but cannot measure bearing strength directly.

A single TV camera is sufficient to confirm the assumption that the surface is smooth and flat*.

1001 - soft, smooth, flat, and nonuniform

This coding suggests a surface having a bimodal distribution of bearing strength, with some areas soft as in surface 1000, and some areas relatively hard. Here it is necessary to map the hard and soft areas, in the hope that a hard area of twice the LEM CEP diameter can be found. Such a mapping operation is best done by a roving vehicle, although the instrument carried might be a simple "go-no go" device.

The coding might also describe a surface which has both areas covered with highly incompetent dust (clearly incapable of supporting the LEM) and areas whose bearing strength is close to the minimum needed to support the LEM. In this case, the rover would require both a penetrometer for the mapping operation and a bearing strength instrument to obtain the necessary statistical distribution of bearing strength of the more competent areas.

It is clear that certifying surfaces such as these depends strongly on a roving vehicle; a fixed Surveyor, even equipped with a large number of simple launchable accelerometers, would be unlikely to succeed.

As with surface 1000, a single TV camera is sufficient to confirm the assumption that the surface is smooth and flat*.

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* It is insufficient to make definitive measurements if the assumption is incorrect, since stereo (perhaps with elevated cameras) would then be required.

4.0 ALTERNATE PAYLOADS

The instruments listed under the various surfaces in the preceding section and in Appendix A are not all simultaneously necessary. Neither are they simultaneously possible, with the present maximum Surveyor payload weight. The largest and heaviest instrument in the list is the rover, which is assumed to have a penetrometer and a single TV camera* on it. Since the rover's estimated weight is close to the total Surveyor payload capacity, it is natural to consider it alone, as an alternative to a completely instrumented fixed Surveyor.

Let us consider, then, two alternate payloads:

a) Fixed Surveyor: Surveyor bus equipped with two TV cameras which can be elevated (50 lb), a bearing strength instrument (15 lb), a penetrometer (3 lb), ten omnidirectional accelerometers (25 lb), a site marker (active or passive) to facilitate location of the Surveyor by the LEM (5-35 lb), and a payload wiring harness (12 lb); these total 110 to 140 lb.

b) Rover: roving vehicle equipped with a penetrometer or bearing strength instrument, a TV camera, and a site marker (active or passive); weight 100 to 150 lb.

Clearly two surfaces can be certified by either payload: the "Daytona Beach" surface (0000) and the soft, smooth, flat, and uniform one (1000). These are the easiest surfaces to certify.

It is also clear that the rover is more effective than the fixed Surveyor on some surfaces, and the fixed Surveyor is more effective on others. The rover is superior

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* Stereo can be obtained by taking two pictures of the same subject from different locations.

on a smooth but hilly surface (X01X), where even the elevated TV cameras of the Surveyor may be blocked, since the rover can go around the hills. The fixed Surveyor's stereo TV is better able to measure surface obstacles over a rough flat area (X10X) than is the rover, which may be immobilized by the roughness. The rover is superior for surface 1000, and much more so for surface 1001 (which may have a distant hard-surfaced area).

Some of the surfaces (those which are both rough and hilly, X11X) might be sufficiently inhospitable that either of the payloads would be inadequate to discover and certify a possible safe landing site. In such cases it would be necessary to search for a more desirable region of the moon, or to employ a more powerful site survey tool in the same region.

Finally, one surface (0001) is not considered, since it is a "don't-care" condition -- it cannot exist according to the rules of the coding.

5.0 DISCUSSION OF INSTRUMENTS

Certain parameters of Surveyor instruments are critical to site certification, and should be carefully monitored. Some of these are:

1) TV resolution -- This determines the maximum range at which an object of given size can be detected or measured.

2) stereo boresight accuracy -- This determines the accuracy with which the stereo TV system can measure range from the Surveyor, which is essential for the establishment of good statistics on obstacle distributions over a broad area around the Surveyor. See Appendix C.

3) soil mechanics accuracy -- The major problem here is extrapolation of the measurement by a small probe to surface areas of the diameter of a LEM foot pad (about 3 feet in diameter). This depends on the ratio of the probe diameter to the surface particle diameter.

4) range of rover -- This fixes the area, centered at the Surveyor, over which the rover may travel. Also included here is the total distance which the rover may traverse, but this is much less critical than range.

5) communication with rover -- It is important that the rover have the ability to communicate the results of its observations to earth, either directly or by relay via the Surveyor, whether or not the line of sight to the Surveyor is obscured. This is vital, since much of the value of the rover is its ability to travel beyond hills which obstruct the view of the fixed Surveyor.

6) accurate measurement of rover's travel distance -- A useful mode of operation for the rover is photographing a lunar surface object from two separate points, giving stereo with a wide base. The accuracy of range and size measurement by this stereo depends directly on the accuracy with which the stereo base (the distance traveled between pictures) is known.

The current parameters of various Surveyor instruments are included, for reference, in Appendix B.

The individual surfaces place requirements on the types of measurements as well as on specific parameters of the instruments. For example, different types of soil mechanics measurements are necessary for the following surface softness characteristics:

a) The surface is soft over a broad area, with a bearing strength which is variable and close to the LEM safety threshold. Here the requirement is for sufficient precise measurements to define accurately the statistical distribution of bearing strength.

b) The surface is composed of adjacent hard and soft areas, where the soft areas are too soft for a LEM landing. The necessary measurement could be a low-accuracy one, perhaps even

"go-no go", but taken at enough points to map the area (with an assist from the Surveyor TV and/or the Orbiter).

c) The surface is made of hard bedrock, with a surface overlay much too soft to support the LEM. What is needed here is enough simple depth or penetration measurements to define the statistical distribution of depth of the soft overlay.

These requirements are clearly quite different in concept. It may, however, be possible to combine more than one such requirement into a single measuring instrument.

Another example is the visual measurements. A roving vehicle would demend a quite different TV camera design than would a fixed Surveyor: high resolution is not so important, since the rover could approach the subject; a single camera is sufficient, stereo being obtained by photographing the same subject from two successive rover positions; a low-resolution high-frame-rate mode of operation may be desired to detect motion of rocks stirred up by the rover; and so on.

Other instruments also place requirements on certain measurements. The soil mechanics experiments, for example, are not really complete without detailed observation of their actions by the TV cameras; this viewing is essential to a proper interpretation of the results. Thus the cameras and the soil mechanics equipment must be placed so as to permit such observation.

The importance of a site marker on the Surveyor cannot be overemphasized. Not only does it ensure that the Orbiter and the LEM can find the spot that the Surveyor has

helped certify, but it greatly simplifies the certification job. If the Apollo astronauts could be assured of a functioning beacon on a landed Surveyor at the time they arrive at the moon, they could plan to land quite close to it, and thus the area which the Surveyor must certify would be much smaller. The type of beacon (active or passive) is a matter which needs to be considered in the larger context of Surveyor and LEM design, as well as the Apollo operational plan. Another matter for a tradeoff study would be the possibility of a beacon on a roving vehicle, as opposed to a beacon fixed on the Surveyor and requiring precise location of the rover relative to the Surveyor.

6.0 CONCLUSIONS

This study is an existence proof of the principle of alternate follow-on Surveyor payloads for site certification. An orderly attempt at matching payloads to conceptual surfaces has resulted in two alternate payloads: a Surveyor fully instrumented for photography and soil mechanics measurements, and a Surveyor-carried lunar roving vehicle. Each is superior for some surfaces, but there are other surfaces which cannot be reliably certified by either payload.

The preceding material elucidates two simple principles: the more hospitable the surface, the less difficult is the measurement needed to certify it; further, the more complete the payload, the greater is the confidence that a given surface can be certified.

The study should not be interpreted as a justification for the two specific alternate payloads above -- it is in

some cases an oversimplification, and is merely illustrative of the kind of analysis which must be made, in much more detail, before a logical plan for Surveyor support to Apollo can be developed.

It should be pointed out that the approach used in this paper (that of constructing a complete set of surfaces) can be highly misleading if not interpreted carefully. All of the surfaces are not equally likely to occur.

7.0 ACKNOWLEDGEMENTS

Many of the arguments presented in this paper have originated with others in Bellcomm; those who should be specifically mentioned are C. J. Byrne, R. F. Fudali, B. T. Howard, and D. B. James.

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APPENDIX A

Below is a list of hypothetical lunar surfaces, and a brief description of the measurements and instruments needed to describe each one*. A more detailed analysis of three of the surfaces (0110, 1000, and 1001) is presented in the body of this report.

0000 - hard, smooth, flat, and uniform

This is the ideal lunar surface for a LEM landing. It is hard enough to support the LEM with minimum sinkage, smooth enough to offer no chance of bottoming or tipping the LEM, quite flat compared to the maximum permissible slope for a LEM landing, and uniform over an area comparable in size to twice the LEM CEP.

Here a minimum of instrumentation is needed to certify a site. The surface may be verified as uniformly hard by a single bearing strength or penetrometer measurement, plus a number of accelerometer measurements at a distance from the spacecraft. Since no small-scale roughness is present, this fact may be verified by a single TV camera**; stereo, which would be useful for measuring the size of obstacles, is not needed. Similarly, flatness uniformity over a reasonable azimuth range can also be verified by a single camera**.

0001 - hard, smooth, flat, and nonuniform

This is a "don't-care" condition. It cannot exist.

0010 - hard, smooth, some hills and valleys, uniform

A single bearing strength or penetrometer measurement plus a number of accelerometer measurements are needed to verify hardness; a single TV camera is sufficient to record smoothness, but two are needed to allow geometric measurement of slopes. The two cameras should be elevated considerably above the present location of TV cameras on the spacecraft in order to avoid blockage due to the slopes and hills. A roving vehicle might also be desirable to go beyond the hills; this would require direct communication with earth.

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* All of the instruments listed under a given surface are not simultaneously necessary; see section 4.0, Alternate Payloads.

** Since we are unlikely to be so lucky as to have such a hospitable surface, it would not be reasonable to plan on only one TV camera for one of the payloads. Also, this surface can be certified by any payload capable of certifying a less desirable surface.

0011 - hard, smooth, some hills and valleys, nonuniform

A single bearing strength or penetrometer measurement, plus a number of accelerometers, are needed to verify hardness; a single TV camera is sufficient to verify smoothness, but two (stereo) are needed to allow geometric measurement of slopes. Elevating them is very important here to permit detection of possible flat areas beyond the hills. A roving vehicle might be desirable to to beyond the hills; this would require direct communication with earth.

0100 - hard, small-scale roughness, flat, uniform

The hardness can be verified by a single bearing strength or penetrometer measurement, plus a number of accelerometers. Stereo TV is necessary to measure slopes and the size of obstacles and holes. Good boresight accuracy is essential to permit accurate measurement of range.

0101 - hard, small-scale roughness, flat, nonuniform

The hardness can be verified by a single bearing strength or penetrometer measurement, plus a few accelerometers. Stereo TV is necessary to measure slopes and the size of obstacles and holes. Good boresight accuracy is essential to permit accurate measurement of range.

0110 - hard, small-scale roughness, hills and valleys, uniform

This is a very difficult surface to certify. Hardness can be verified by a single bearing strength or penetrometer measurement, plus a number of accelerometers. Stereo TV is necessary to measure slopes and the size of obstacles and holes, and the cameras should be elevated to permit looking over the hills. A roving vehicle might be desirable to go beyond the hills (this would require direct communication with earth), but the roughness could be severe enough in some areas to immobilize it.

0111 - hard, small-scale roughness, hills and valleys, nonuniform (some areas free of roughness, or some free of hills, or possibly some free of both)

This is another very difficult surface to certify. Hardness can be verified by a single bearing strength or penetrometer measurement, plus a few accelerometers. Stereo TV, with cameras elevated, is necessary to allow measurement of slopes and obstacle sizes. A roving vehicle might be desirable to go beyond the hills, but the roughness could be severe enough in some areas to immobilize it.

1000 - soft, smooth, flat, and uniform

The soft surface is most likely due to a soft overlay on a subsurface that is hard and strong; the critical measurements are then the depth and the bearing strength of the

soft surface material. Accurate multiple bearing strength and/or penetrometer measurements are necessary, which requires an instrumented roving vehicle (unless the surface layer is so soft as to prevent the rover from moving - which is unlikely since in such circumstances the parent Surveyor would probably not have landed successfully). Since the surface is assumed to be flat, the rover could communicate with earth via line-of-sight relay to and from the landed Surveyor. An alternative to the rover, although inferior, is multiple accelerometers launched from the Surveyor, in addition to a fixed accurate penetrometer or bearing strength instrument. The accelerometers can give an indication of the extent of the soft-overlay region, but cannot measure bearing strength directly.

A single TV camera is sufficient to confirm the assumption that the surface is smooth and flat*.

1001 - soft, smooth, flat, and nonuniform (some areas hard)

This coding suggests a surface having a bimodal distribution of bearing strength, with some areas soft as in surface 1000, and some areas relatively hard. Here it is necessary to map the hard and soft areas in the hope that a hard area of twice the LEM CEP diameter can be found. Such a mapping operation is best done by a roving vehicle, although the instrument carried might be a simple "go-no go" device.

The coding might also describe a surface which has some areas covered with highly incompetent dust (clearly incapable of supporting the LEM) and some areas whose bearing strength is close to the minimum needed to support the LEM. In this case the rover would require both bearing strength and penetrometer instruments for the mapping operation.

It is clear that certifying surfaces such as these depends strongly on a roving vehicle; a fixed Surveyor, even equipped with a large number of simple launchable accelerometers, would be unlikely to succeed.

As with surface 1000, a single TV camera is sufficient to confirm the assumption that the surface is smooth and flat*.

1010 - soft, smooth, hills and valleys, uniform

Here a roving vehicle instrumented for accurate bearing strength and/or penetrometer measurements is necessary. Communication to earth should be direct, rather than via the Surveyor, unless a sufficiently tall antenna can be placed on the Surveyor to eliminate the line-of-sight problems. Alternatively, stereo TV is necessary for

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* It is insufficient to make definitive measurements if the assumption is incorrect, since stereo (perhaps with elevated cameras) would then be required.

topographic purposes, and the cameras should be elevated to permit looking beyond the hills.

1011 - soft, smooth, hills and valleys, nonuniform (some areas hard and/or flat)

The same instrumentation as for surface 1010 is necessary, except that the need for a rover to travel beyond the hills to a possible desirable site must be even more strongly emphasized. This rover should be capable of direct communication with earth, if possible.

1100 - soft, small-scale roughness, flat, uniform

A single accurate bearing strength and/or penetrometer measurement, plus a large number of accelerometers, are the minimum necessary to evaluate the soft surface overlay. A roving vehicle equipped with an accurate penetrometer or bearing strength device would be much more desirable, but the roughness could be severe enough in some areas to immobilize it.

Stereo TV is necessary to measure the size and distance of small obstacles and holes.

1101 - soft, small-scale roughness, flat, nonuniform (some areas hard and/or smooth)

The same instrumentation as for surface 1100 is necessary, except that a rover (to travel to possible hard and/or smooth areas) is even more desirable. Possible immobilization of the rover due to surface roughness must still be considered. This rover could communicate with earth via line-of-sight relay to and from the landed Surveyor.

1110 - soft, small-scale roughness, hills and valleys, uniform

A single accurate penetrometer or bearing strength measurement, plus a large number of accelerometers, are the minimum necessary to evaluate the soft surface overlay. A roving vehicle equipped with a penetrometer or bearing strength device would be much more desirable (and would go beyond the hills as well), but the roughness could be severe enough in some areas to immobilize it.

Stereo TV is necessary to measure slopes and the size and distance of small obstacles and holes, and the cameras should be elevated to permit looking beyond the hills.

This is the most difficult surface to certify for a safe Apollo landing.

1111 - soft, small-scale roughness, hills and valleys, nonuniform (some areas hard and/or smooth and/or flat)

The same instrumentation is needed as for surface model 1110, except that the promise of a distant satisfactory site makes the rover even more desirable (although nonetheless constrained by roughness).

APPENDIX B

SURVEYOR INSTRUMENT PARAMETERS

Surveyor TV System
(Surveyor System Functional Requirement No. 224510-
Hughes Aircraft Co.)

resolution = 0.25 mr/TV line

system S/N (peak video/rms noise), for low line frequencies: 27db.

relative aperture: f/4

white line (chart luminance: 100 foot-lamberts)

aperture controllable from f/4 to f/22

camera elevation: 4 ft. minimum

elevation range: -45° to +15°

raster: 600 active lines

field of view: 6.4° x 6.4°

resolution: $\geq$ 70 optical pairs/mm

Surveyor Elevated TV
(JPL TM #33-56)

maximum elevation 12.2 m.

horizon at 6.5 km

area seen 130 km^2

compared to elevation of 1.22 m

horizon at 650 m

area seen 1.3 km^2

boresight error $\doteq$ 1 minute of arc = 0.291 mr
(this is nearly the same as the resolution)

compared to present error of perhaps 1°

Surveyor Penetrometer

penetration depth - 20"

bearing pressure - 10 psi/ft - 30 psi max.

weight - 3# one shot

Surveyor Roving Vehicle

4 or 6 wheels, all driven

100# earth weight

1 TV camera carried

soil mechanics experiment carried

range 1 mile

specified surface (soft): 0 psi b.s. at surface increases linearly at 1 psi/ft.

successful bidders: Bendix and General Motors

GM Rover Specifications (for example)

wheel diam: 18" (6 wheels) length 6'

bearing pressure: 0.065 psi width 3'

ground clearance: 6" minimum weight 12.5# (lunar)

can cross a 30" vertical step

can span a 20" crevice

Accelerometer Balls

fixed weight: 5#

weight per shot: 2#

for a material having a 10 psi bearing strength:

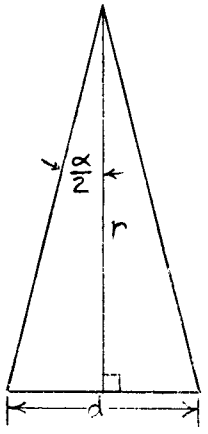
$a = 30$ g (assumes penetration until the full diameter of the ball is effective)

to find depth of penetration: $v_o^2 = 2as$

for $v_o = 30$ ft/sec, $\underline{s \doteq 0.5 \text{ ft}}$.

APPENDIX C

SURVEYOR BORESIGHT AND RANGING ACCURACY



$$r = \frac{d}{2} \cot \frac{\alpha}{2}$$

$$dr = -\frac{d}{4} \csc^2 \frac{\alpha}{2}\, d\alpha$$

$$\frac{dr}{r} = -\frac{1}{\sin\alpha}\, d\alpha$$

for $r >> d$, $\sin\alpha \doteq \tan\alpha \doteq \frac{d}{r}$

Then $\left| \frac{\Delta r}{r} \right| \doteq \frac{r}{d} \Delta\alpha$

The range accuracy is therefore proportional to the boresight accuracy $\Delta\alpha$. Using d = 1.2 m and $\Delta\alpha = 1°$ (for the present Surveyor TV*),the range for a range accuracy of 20% is:

$$r = \frac{d}{\Delta\alpha} \left| \frac{\Delta r}{r} \right| = \frac{1.2}{1/57.3°} \quad (0.2) = 13.8 \text{ meters}$$

Using $\Delta\alpha = 1'$ (for the elevated TV*), r = (60)(13.8) = 825 meters.

The range accuracy is important to site certification for two reasons: it affects the precision of measurement of the area over which Surveyor can estimate obstacle density (and thus the precision of the estimated density), and it affects the accuracy with which the TV can measure obstacle size.

Let s = size (diameter) of an object

r = range (distance of object from Surveyor)

β = angle subtended by object at Surveyor.

Then $s = r\beta$

$$\Delta s = r\Delta\beta + \beta\Delta r = r\Delta\beta + s\left(\frac{\Delta r}{r}\right) = r\Delta\beta + s\left(\frac{r}{d}\Delta\alpha\right)$$

$$\frac{\Delta s}{s} = \left(\frac{\Delta\beta}{s} + \frac{\Delta\alpha}{d}\right) r$$

For $\Delta\beta = 0.25 \times 10^{-3}$ rad. (TV line resolution)

$\Delta\alpha$ = 1 degree = 0.0174 rad.

$$\frac{\Delta s}{s} = \left(\frac{0.25 \times 10^{-3}}{0.5} + \frac{0.0174}{1.2}\right) r = 0.015r$$

Then the range at which the accuracy is 20% is:

$$r = \frac{0.2}{0.015} = \underline{13.3 \text{ meters}}$$

For $\Delta\alpha$ = 1 minute of arc = 0.291×10^{-3} rad.:

$$\frac{\Delta s}{s} = \left(\frac{0.25 \times 10^{-3}}{0.5} + \frac{0.291 \times 10^{-3}}{1.2}\right) = 0.74 \times 10^{-3} r$$

and the size measurement accuracy is 20% at

$$r = \frac{0.2}{0.74 \times 10^{-3}} = \underline{270 \text{ meters}}.$$